

Design of a GIS-based Assistant Software Agent for the Incident Commander to Coordinate Emergency Response Operations

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Abstract—Problem: This paper addresses the design of an intelligent software system for the IC (incident commander) of a team in order to coordinate actions of agents—field units or robots—in the domain of emergency/crisis response operations.

Objective: This paper proposes GICoordinator. It is a GIS-based assistant software agent that assists and collaborates with the human planner in strategic planning and macro tasks assignment for centralized multi-agent coordination.

Method: Our approach to design GICoordinator was to: analyze the problem, design a complete data model, design an architecture of GICoordinator, specify required capabilities of human and system in coordination problem solving, specify development tools, and deploy.

Result: The result was an architecture/design of GICoordinator that contains system requirements.

Findings: GICoordinator efficiently integrates geoinformatics with artificial intelligent techniques in order to provide a spatial intelligent coordinator system for an IC to efficiently coordinate and control agents by making macro/strategic decisions. Results define a framework for future works to develop this system.

I. INTRODUCTION

The domain of emergency/crisis response is concerned with reducing number of fatalities in the first few days after disaster (natural or human-made), and USAR (Urban Search and Rescue) has a significant issue in this domain. A disaster response team, which contains an IC and several agents, is faced with the problem of carrying out geographically dispersed tasks under evolving execution circumstances in a manner that achieves a high-level objective in a minimum time. Agents need to efficiently coordinate their actions with each other in order to maximize the objective function. Effective coordination is an essential ingredient for efficient emergency response management but it is difficult to achieve.

It is important for the IC, who has a big picture of the state of the world, to coordinate and control agents. His main role is to make a strategic action plan, allocate tasks to agents, decide on actions of agents, and schedule activities of agents in time and space.

To propose an ideal system, some requirements should be considered as follows. The decision-maker is the IC, therefore coordination is a centralized approach but execution of tasks is distributed among agents. Tasks information that

forms the IC's global perception has the spatial, macro, dynamic, and temporal characteristic; it means that these data should be used in related algorithms. Planning, task assignment, and scheduling techniques in multi-agent systems are used for problem solving. Methods which are applied should partially constrain agents with macro decisions and permit agents to adapt their activities and make their own tactical (micro) decisions according to real situations. Because of the geographic characteristic of the problem, GIS (geographic information systems) are required to support human decisions by providing a set of proper tools for management, analysis, modeling, and visualization of geographic information and location-based information. A mixed-initiative system can be proper system for the IC.

This requires an ideal intelligent software system to assist the IC and collaborate with him in strategic planning and tasks assignment to agents according to the assessed requirements.

Although there is much literature [1], [2], [3] in planning, coordination, task assignment, human-machine collaboration, problem-solving algorithms, and decision making under uncertainty, unfortunately, the discussed requirements have not been thoroughly addressed by the previous works.

Designing an ideal approach is an important phase in system development. As a result, in order to develop an ideal system, this paper aims to design GICoordinator. GICoordinator is a GIS-based assistant software agent that assists and collaborates with the human planner in strategic planning and macro tasks assignment in the mixed-initiative approach. This paper summarizes phases that make up this system.

II. SYSTEM DESIGN

This section is dedicated to phases which are important to design the GICoordinator.

A. Analyze the Problem

First step is to completely analyze and describe the problem. Essential dimensions that compose this problem include: the problem domain, the structure of a team, geographic information, macro tasks, requirements, assumptions, the goal function, the strategic action plan, and the macro task schedule [4].

B. Design the Architecture of GICoordinator

The architecture of GICoordinator is designed based on integration of three key components as Fig. 1 shows. Table 1 defines the required functionalities of GICoordinator and human according to the analyzed problem. The following subsections briefly describe some important capabilities.

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TABLE I
SYSTEM REQUIREMENTS: THE DESIRABLE CAPABILITIES OF
GICoordinator AND HUMAN

Component	Functionalities
Human	1- Specify high-level strategies for coordination of agents 2- Revise and refine strategies
Spatial Database	3- Organize data (geographic, location-based, and non-geographic) of the problem 4- Integrate the software agent with GIS 5- Support information sharing with agents and with other information systems, and support integration of information systems
GIS	6- Support human decisions by providing tools for geospatial reasoning, geographic information management and visualization 7- Support the software agent by providing GIS analysis 8- Interact with human
Software Agent	9- Assign agents (field units) to human high-level strategies in strategic planning 10- Assign geospatial-temporal macro tasks to agents in centralized scheduling 11- Adapt and revise the strategic decision 12- Adapt and revise the schedule 13- Search for an optimal plan 14- Allocate resources (refuges) to damage points under human strategies 15- Adjust and refine human strategies 16- Provide an interface to interact with human 17- Percept and observe the environment via the spatial database

1) *Provide GIS Analysis:* GICoordinator provides geotechnologies and geo-informatics that support human decisions and increase functionality of the software agent. Three significant purposes are of importance: (1) visualization of information via 3D maps or thematic maps e.g. display spatial distribution of tasks, states of macro tasks, action plans, and tasks schedule, (2) geospatial reasoning that includes spatial relationships analysis, network analysis, proximity analysis, etc, and (3) information management that includes retrieval, insert, query, update, and manipulate information of spatial database. It enables the IC to interact with geographic information, and it supports human decisions by providing a better situational awareness.

GICoordinator requires necessary information for computation because it is mainly focus on multi-agent coordination techniques. Different types of information are provided by distributed systems. Therefore GICoordinator requires an-

other capability to gather, integrate, mine, or fuse data from distributed databases. This version of GICoordinator does not include this functionality.

2) *Strategic Planning:* It is an approach in an organizational structure to make a strategic plan that states that how agents can get from the current state of the world through a sequence of actions to a desired goal state. Strategic planning in a disaster response team includes (1) specify a response objective (a high-level strategy) for the team and decompose it into prioritized sub-goals (threads), (2) make a strategic decision by assignment of agents to threads, and (3) evaluate and adapt a strategic decision to new crisis situations [3].

This capability calculates a set of right choices for making a strategic decision either in execution of the human strategy or in adaption of current assignments [5]. These choices are presented for the IC to select the best choice according to his intuition or to delegate the system to search for the optimal one. Moreover, the system autonomously releases right agents from a right thread in a right time during tasks execution in order to revise the strategic decision.

3) *Centralized Scheduling:* This capability is required to dynamically assign spatial-temporal macro tasks to agents under human strategic decisions in centralized scheduling in order to minimize the overall time of tasks execution. Two main results are achieved by running this algorithm: (1) a feasible schedule and (2) an adaption time. A schedule is composed of a number of macro decisions that specify: (1) what task type is going to be done, (2) who (a subset of agents) are assigned to do this assignment, (3) where (a macro geographic object) contains a subset of tasks, (4) when operations start, (5) when operations finish, (6) how many tasks are estimated to be done, and (7) what task types and how many of them are estimated to be revealed in this location after to finish this job [6].

4) *State-Space Search:* This capability calculates an optimal strategic plan, a complete schedule, and a overall minimum time of tasks execution. It evolves assignment of agents to threads from an initial state to a specified goal state. Results state that how and when agents can reach a defined objective. These results support human decisions and assist the IC to evaluate the quality of his strategy, refine it, or define a better strategy.

5) *Resource Allocation:* This capability optimally allocates available refuges to rescued people in medical transportation operations according to human strategic decisions. Results state that which injured persons should be transported to which refuges in order to optimize an objective function.

6) *Adjustment of Human Strategies:* It is difficult for an IC to specify a good strategy and timely revise it during emergency management. An IC may specify a bad or wrong high-level strategy that leads to a very big catastrophe with significantly severe consequences. This capability recommends human for adjustment and refinement of his strategy in real-time.

System should resolve trade-off of resource/role assignments and reflect feed back from actual damaged area. This system requirement should consider them. Machine learning

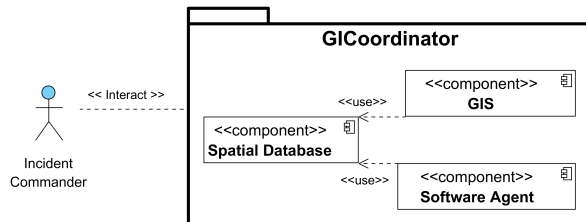


Fig. 1. The architecture of GICoordinator

TABLE II
REQUIREMENT TOOLS FOR DEVELOPMENT OF THE GICoordinator

Component	Tools
Spatial Database	Microsoft Spatial SQL Server, GeoDatabase, the data model
GIS	ArcGIS, .NET Programming
Software Agent	C#.NET Programming, ArcObjects, the data model

algorithms can provide proper solution. We will devote a paper to this functionality.

C. Design the Data Model

It is important to model, formulate, and present data of the problem completely. The data model presents elements of this problem, properties, relationships, and interaction among these elements with regard to problem data modeling. This data model is important to support development of GICoordinator and implementation of the capabilities designed for this system [4].

The designed data model only formulates the planning & scheduling problem which the IC is faced, although spatially distributed agents can observe, gather, and report many types of information from their local environment to the incident center. Uncertainties are presented by proper attributes of classes of this data model, and they are used by related algorithms.

This data model formulates and present any USAR operations and similar crisis operations. It, also, formulates a team of different agents. The size of a team and the size of disaster scenario are scalable, but it is important to model any required information in the data model.

D. Development tools

There are many tools and approaches that can be used to implement and develop a system. In our methodology, Table 2 shows required tools that were used to develop GICoordinator. It states that how each component should be implemented and developed.

We applied the C#.Net programming language for developing GICoordinator. Algorithms, the structure of the system, and rules were implemented in the program. All system requirements, which are defined in Table 1, were implemented by the developer using the specified development tools.

There is a key concern in development of GICoordinator. The designed data model was used to develop his system, and there are interdependencies among functions of the system. All functions should be run in an integrated system. Any change in the data model may cause that the system does not work.

E. Deploy

GICoordinator is deployed in two ways. First one is to calculate an feasible strategic plan & schedule, which partially specify actions of agents, by the human-system

collaboration before execution. Second one is to use this system for automated and autonomous adaption/refinement of macro/strategic decisions to new situations during execution and in real time.

As Fig. 1 shows, the GIS and the software agent have a connection to the spatial database. In order to run GICoordinator, the spatial database, whose structure is based on the designed data model, has to contain essential information of the initial state of the world. These data can insert or modified by the human via the user-interface that GICoordinator provides for human-system interaction [4].

III. RESULTS

The result was an architecture/design of GICoordinator that contains system requirements.

IV. CONCLUSION

The design of GICoordinator was discussed in this paper. The key insight is (1) support human decisions with geo-spatial intelligent software system, (2) provide A.I. techniques for strategic planning, macro tasks assignment, scheduling, and automated adaption of these decisions in central multi-agent coordination, (3) involve human in the loop and enable collaboration between human and system for decision making. Future works will be to address the defined capabilities of GICoordinator by several papers.

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